RHIC Polarimetry: Status and Plan

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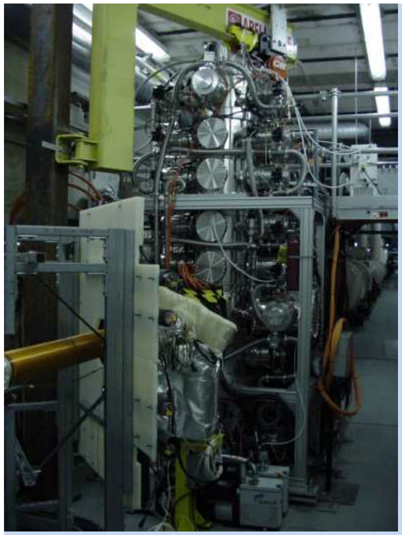
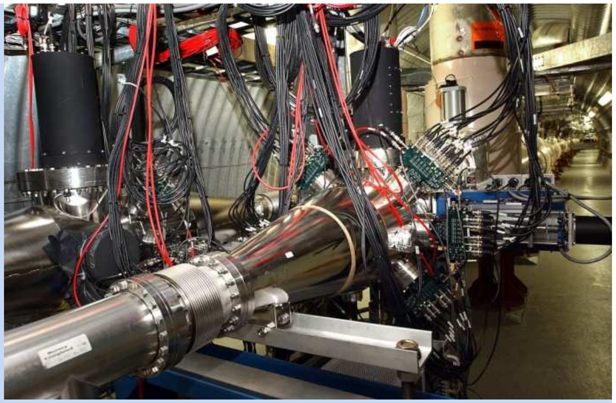
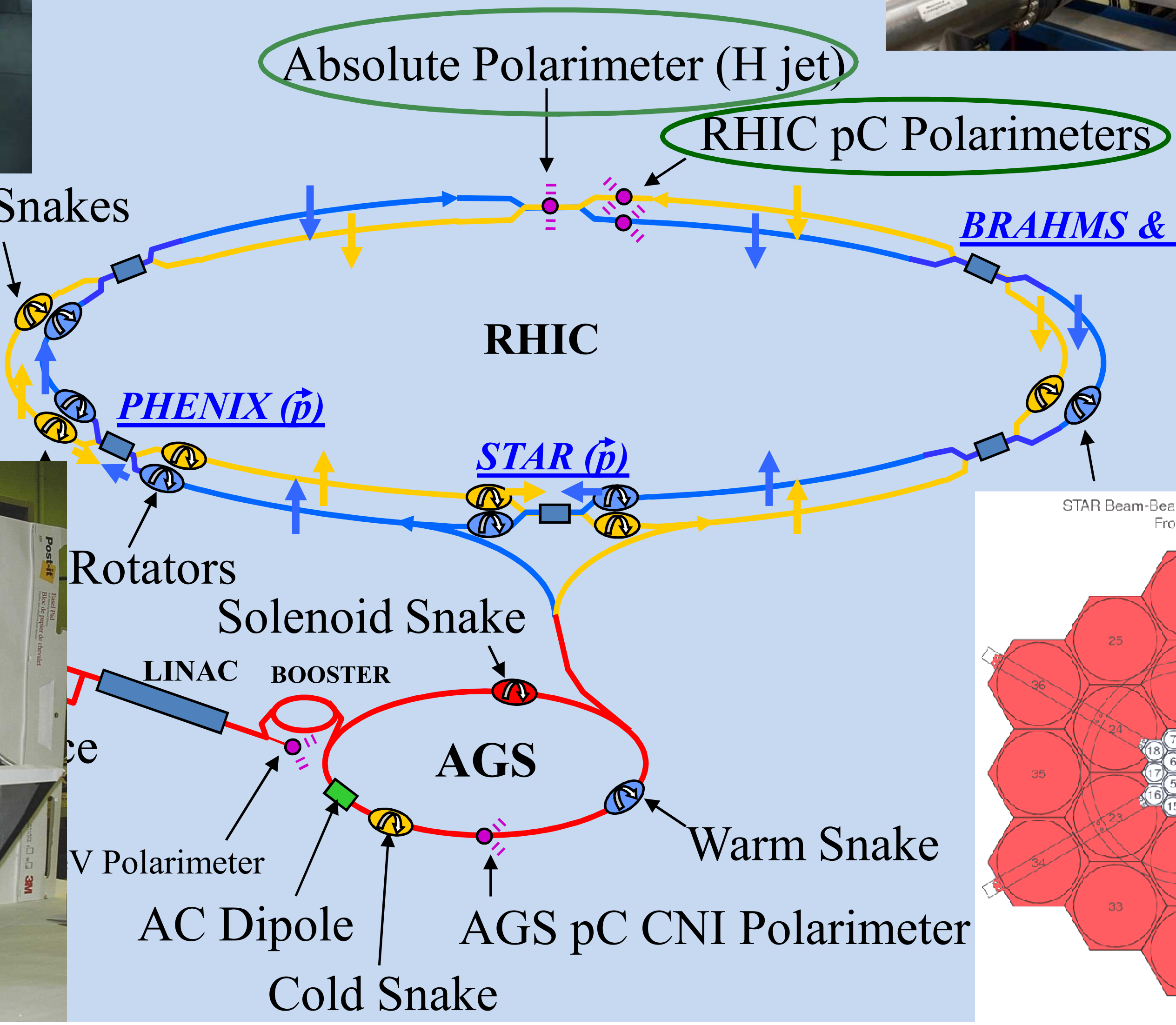
For the RHIC Polarimeter Group

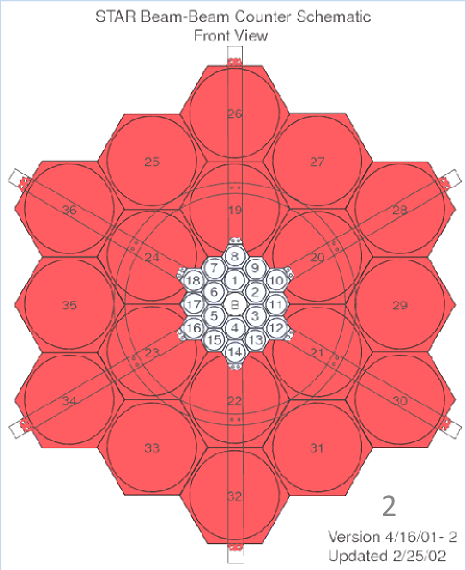
RHIC&AGS Annual Users' Meeting 26 May 2010

RHIC and Polarimetry

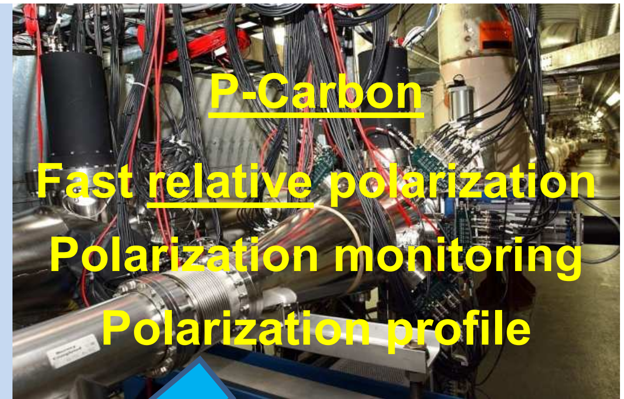








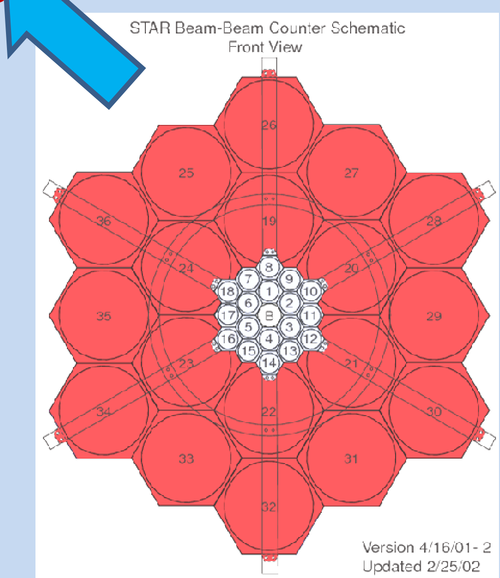
RHIC and Polarimetry



- Precise beam polarization measurements for RHIC experiments (value and direction)
- Fast feedback for polarized beam setup, tune and development

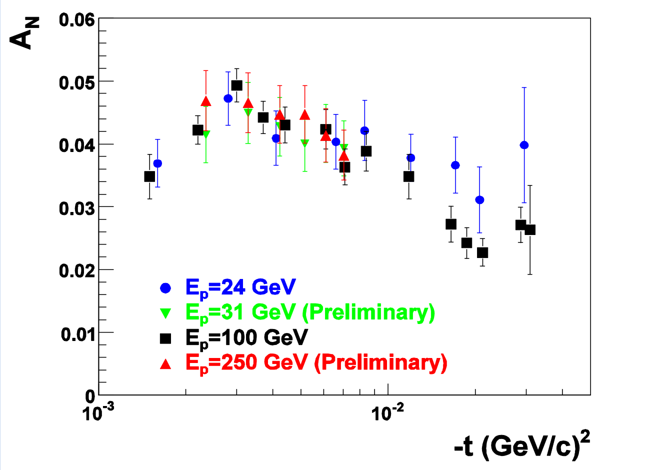
Local Polarimeters

Monitor spin direction at collision (confirmation of long. polarization)



Polarized H-Jet Polarimeter

$$A_N = \frac{1}{P}\frac{N_L - N_R}{N_L + N_R} = \frac{\varepsilon}{P}$$

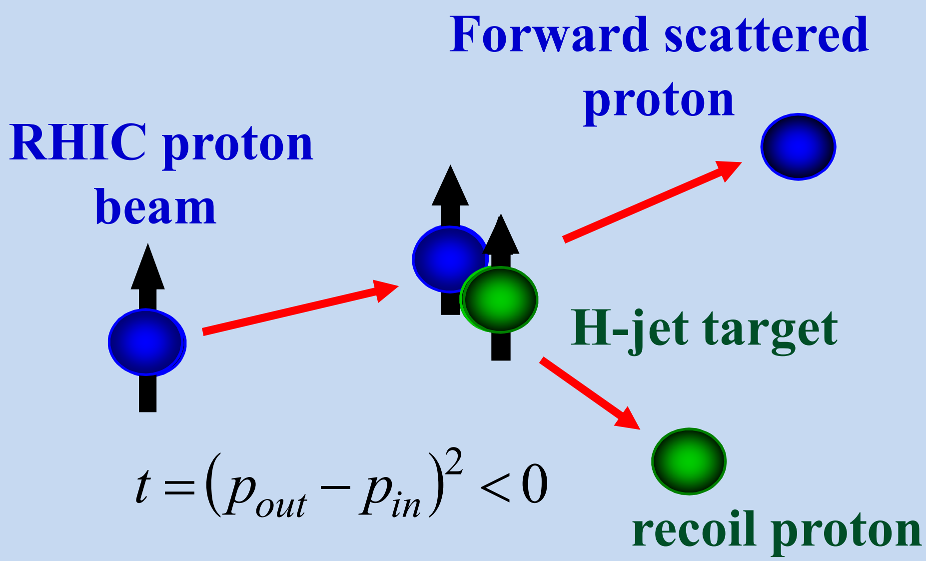


Left-right asymmetry in elastic scattering:
Interference between electromagnetic and hadronic amplitudes in the Coulomb-Nuclear Interference (CNI) region

Beam and target are both protons

$$A_N(t) = \boxed{-\frac{\varepsilon_{\text{target}}}{P_{\text{target}}}} = \boxed{\frac{\varepsilon_{\text{beam}}}{P_{\text{beam}}}}$$

$$\Rightarrow \boxed{P_{beam} = -P_{\text{target}}\frac{\varepsilon_{beam}}{\varepsilon_{\text{target}}}}$$

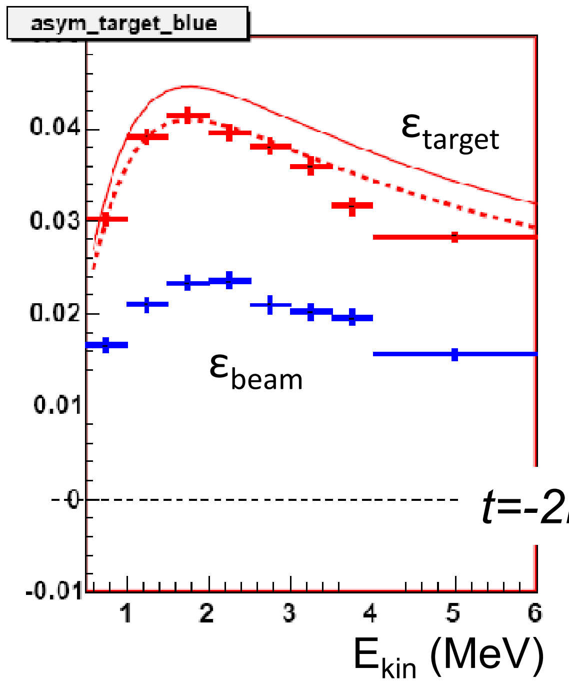


$$t = (p_{out} - p_{in})^2 < 0$$

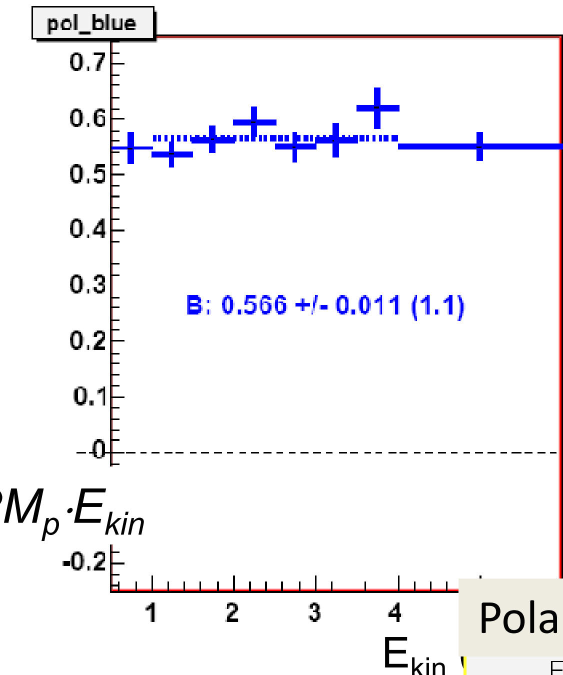
P_{target} is provided by Breit Rabi Polarimeter

H-Jet:

Example from Run6

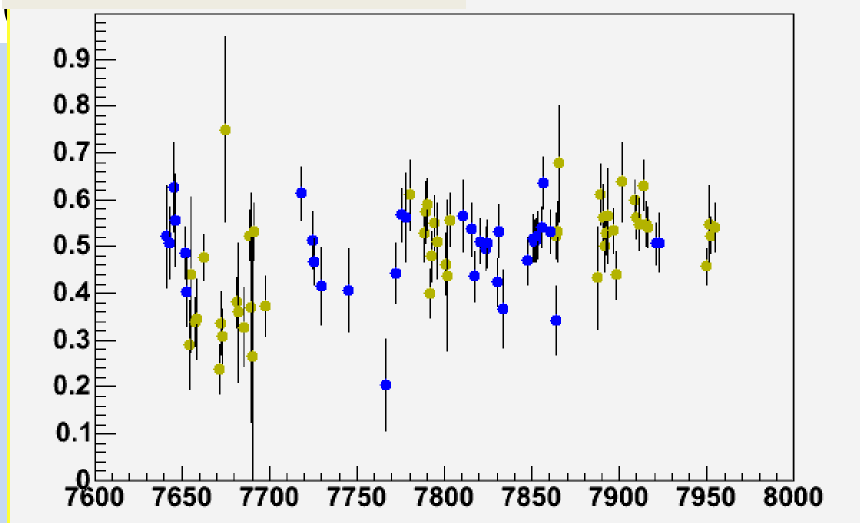


$t=-2M_p \cdot E_{kin}$



$$\frac{P_{beam}}{P_{target}} = \frac{\varepsilon_{beam}}{\varepsilon_{target}}$$

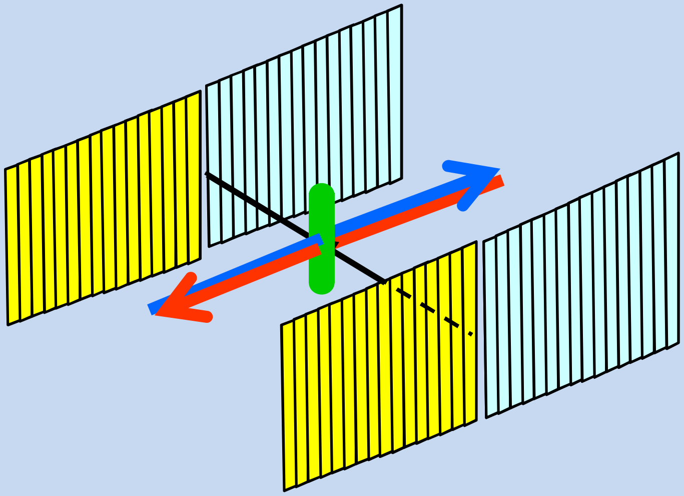
Polarization vs fill



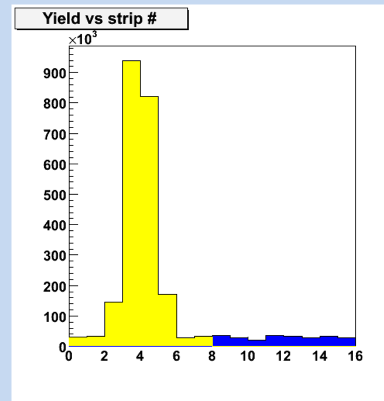
Measures average over beam profile polarization with fill-by-fill stat. uncertainty ~7-10%

Data accumulated for a few fills provide normalization for pC polarimeter with stat. uncertainty <<5%

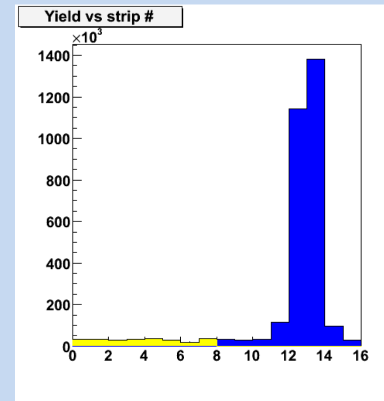
H-Jet: From one to two beam measurements



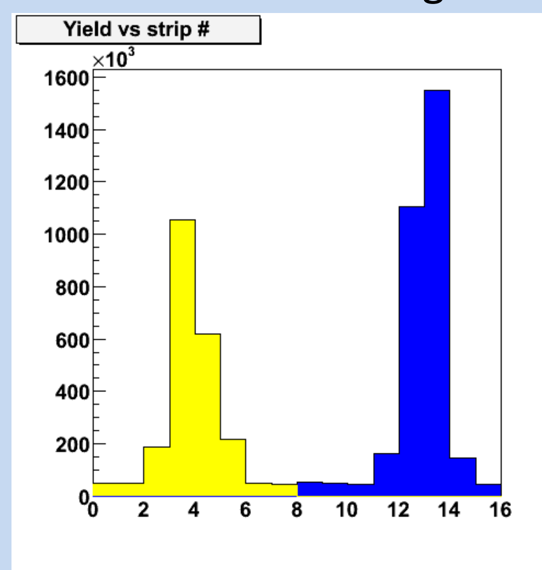
Yellow beam on target



Blue beam on target



Both beams on target



Successfully tested in Run2008 and routinely used in Run2009

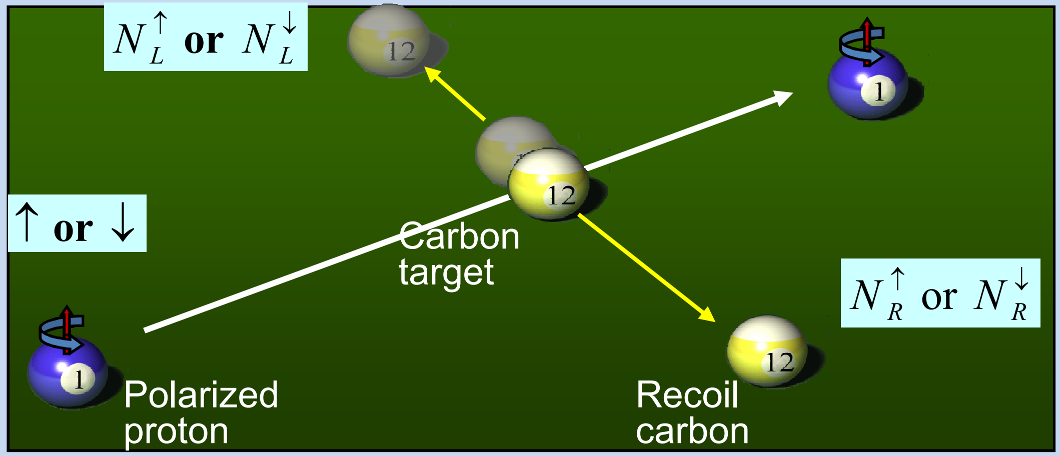
- ✓ Background level slightly increased as expected compared to single beam mode
- ✓ Allows to monitor both beam polarizations by H-Jet simultaneously in all fills
- ✓ Doubles accumulated statistics

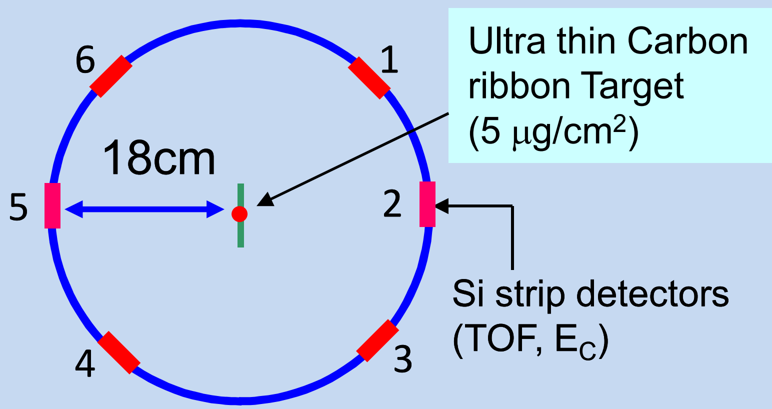
P-Carbon Polarimeter:

Left-right asymmetry in elastic scattering: Interference between electromagnetic and hadronic amplitudes in the Coulumb-Nuclear Interference (CNI) region

$$P_{beam} = -\frac{\varepsilon_N}{A_N^{pC}}$$

$$\varepsilon_N = \frac{N_L - N_R}{N_L + N_R}$$





Target Scan mode (20-30 sec per measurement)

Stat. precision 2-3%

4-5 measurements per fill (every 2-3 hours)

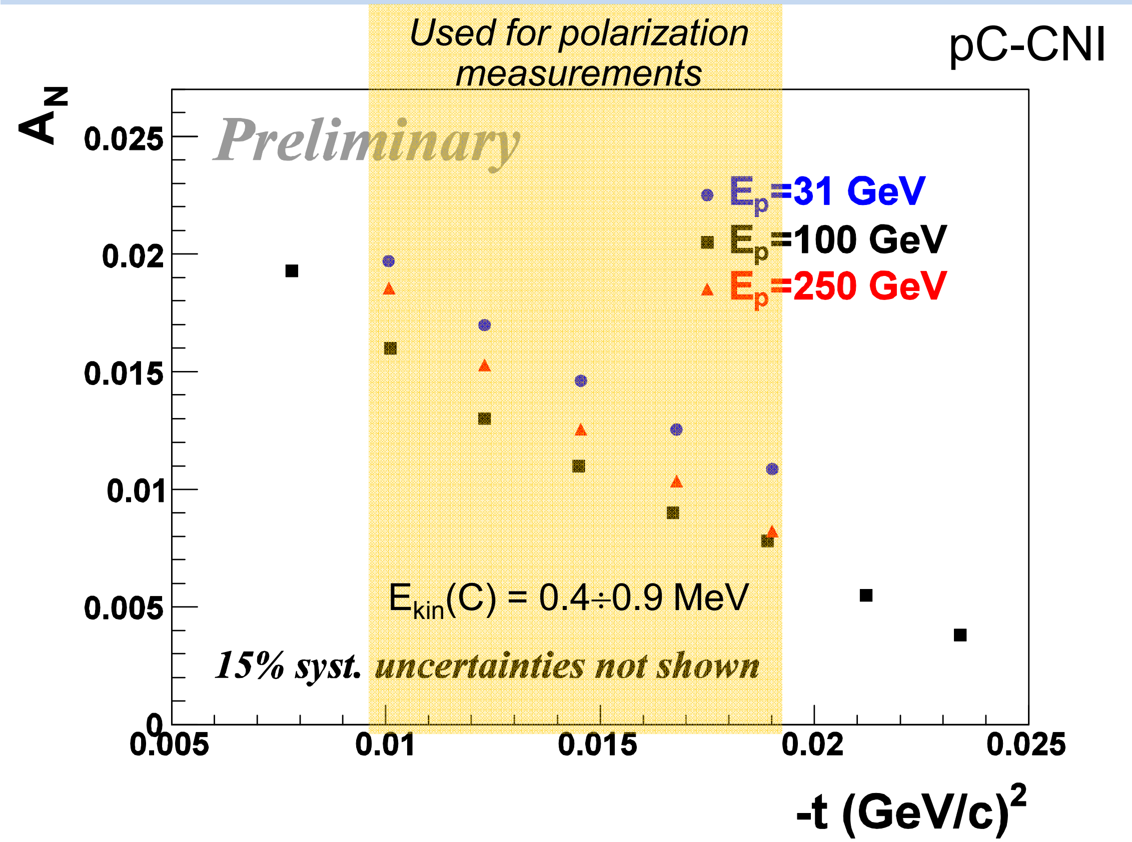
Polarization profile, both vertical and horizontal

Normalized to H-Jet measurements over many fills

pC: A_N

$$P_{beam} = -\frac{\varepsilon_N}{A_N^{pC}}$$

$$\varepsilon_N = \frac{N_L - N_R}{N_L + N_R}$$



Sizable analyzing power in wide proton beam energy range (with weak energy dependence)

⇒

pC elastic scattering in CNI region is ideal for polarimetry in wide beam energy range

E_{kin} range – the major source of syst. uncertainty for A_N

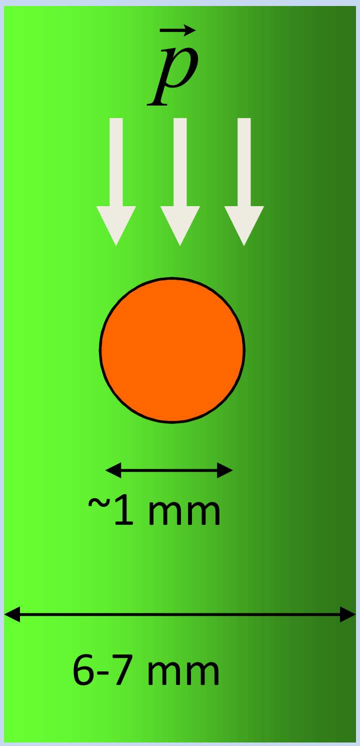
⇒

Re-normalize pC A_N for a fixed E_{kin} range every Run (for a given pC setup) using H-Jet

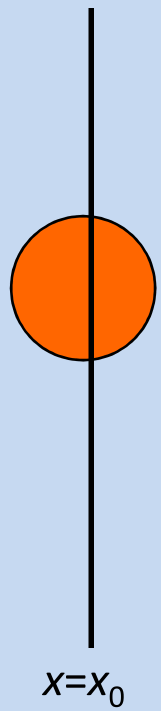
Poarization Profile

If polarization changes across the beam, the average polarization seen by Polarimeters and Experiments (in beam collision) is different

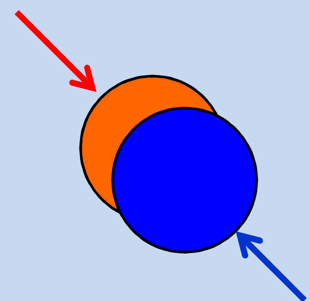
H-Jet



pC



Collider Experiments

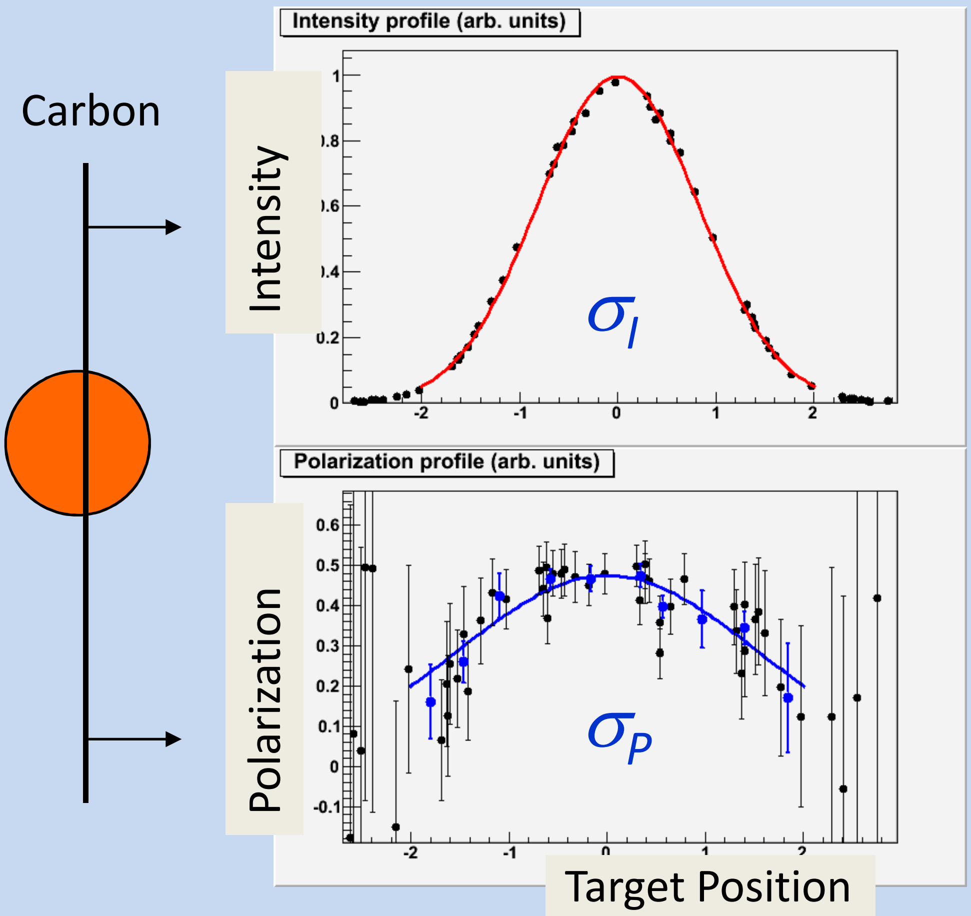


$$\langle P_1 \rangle = P_1(x,y) \otimes I_1(x,y) \qquad \langle P_1 \rangle = P_1(x_0,y) \otimes I_1(x_0,y) \qquad \langle P_1 \rangle = P_1(x,y) \otimes I_1(x,y) \otimes I_2(x,y)$$

$P_{1,2}(x,y)$ – polarization profile, $I_{1,2}(x,y)$ – intensity profile, for beam #1 and #2

Pol. Profile and Average Polarization

Scan C target across the beam
In both X and Y directions



$$R = \frac{\sigma_I^2}{\sigma_P^2}$$

$$\frac{\langle P \rangle_{Exp}}{\langle P \rangle_{HJet}} = \frac{\sqrt{(1+R_X)\cdot(1+R_Y)}}{\sqrt{\left(1+\frac{1}{2}R_X\right)\cdot\left(1+\frac{1}{2}R_Y\right)}} \approx 1 + \frac{1}{4}(R_X + R_Y)$$

Ideal case: flat pol. profile ($\sigma_P = \infty \Rightarrow R = 0$)

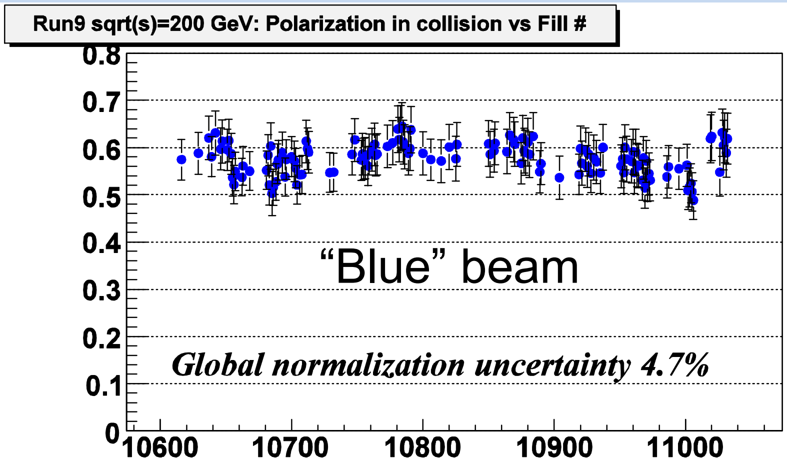
Run9:

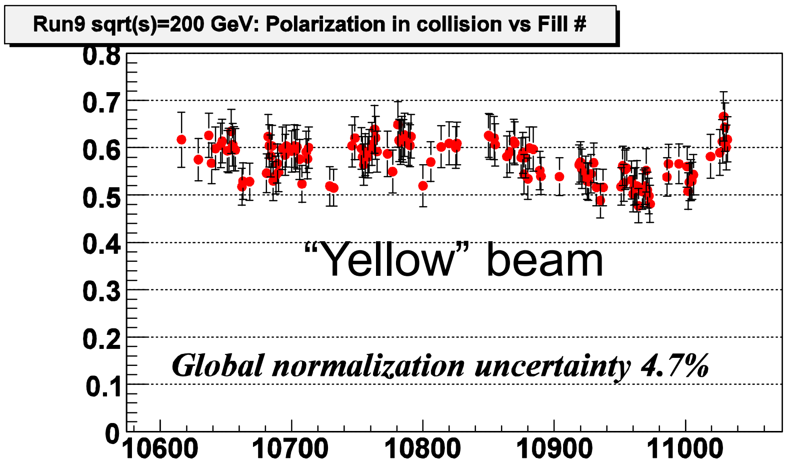
$\sqrt{s}$=200 GeV: R~0.1 $\Rightarrow$ 5% correction

$\sqrt{s}$=500 GeV: R~0.35 $\Rightarrow$ 15% correction

pC+HJet: Polarization vs Fill

Run-2009 results ($\sqrt{s}$=200 GeV)





- ✓ Normalized to Hjet
- ✓ Corrected for polarization profile

$\delta P/P < 5\%$

Dominant sources of syst. uncertainties:

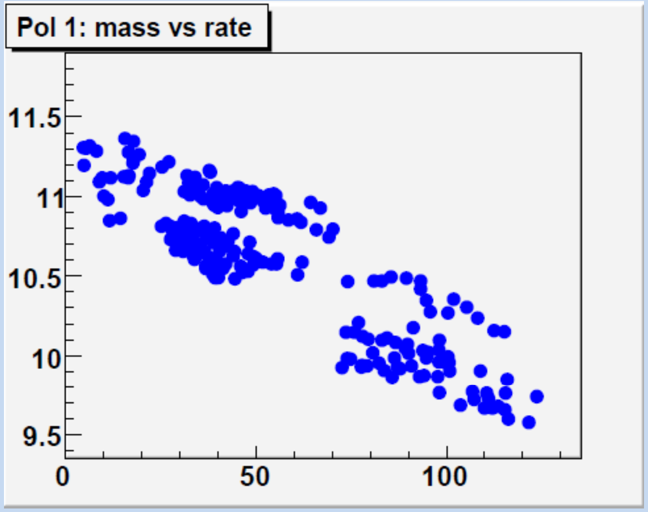
- ~3% - HJet background
- ~3% - pC stability
  (rate dependencies, gain drift)
- ~2% - Pol. profile

$\sqrt{s}$=500 GeV: $\delta P/P \sim 10\%$ (P ~ 0.4)

Due to higher rates and sharper pol. profile

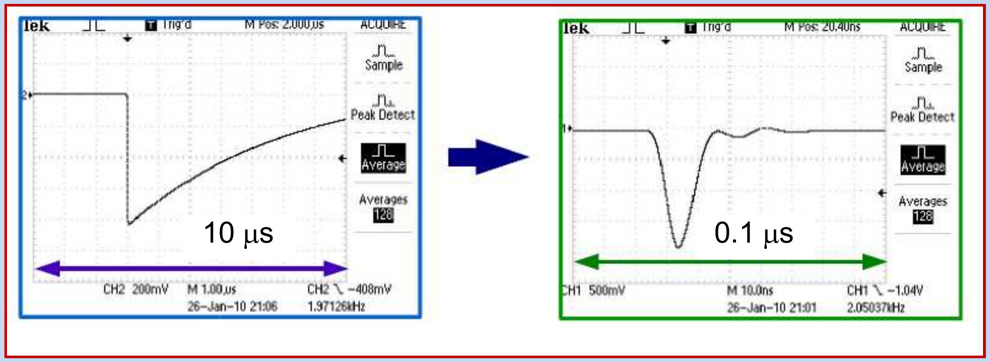
Rate related systematics in Run9 and solution

Run9, $\sqrt{s}$=500 GeV:
$M \propto E \cdot ToF^2$ vs Rate (kHz/strip)



Old amplifier

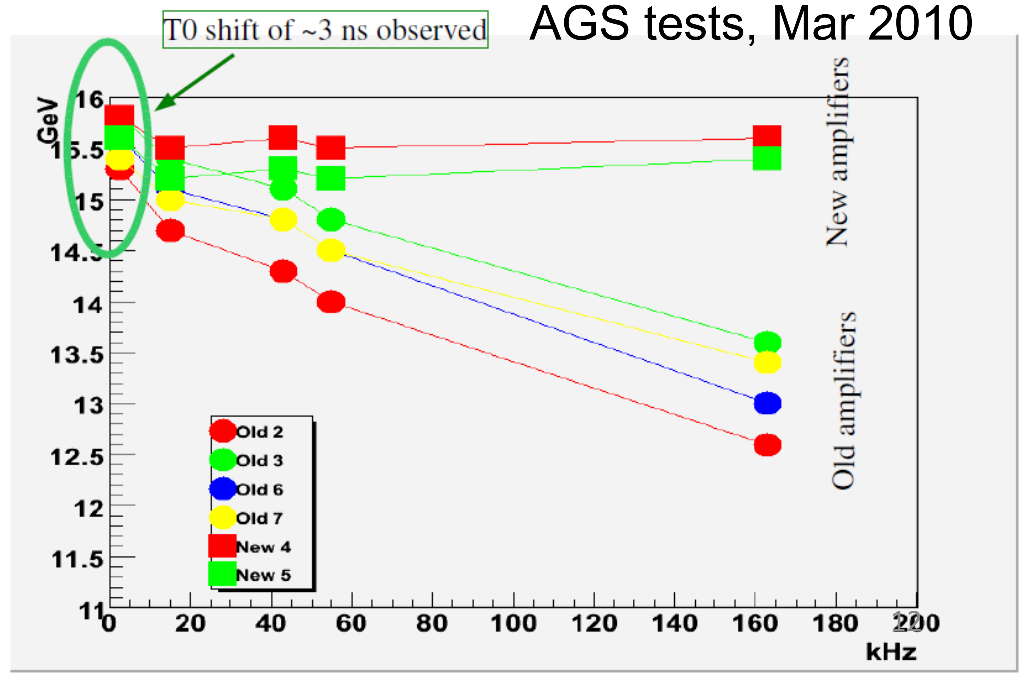
New amplifier



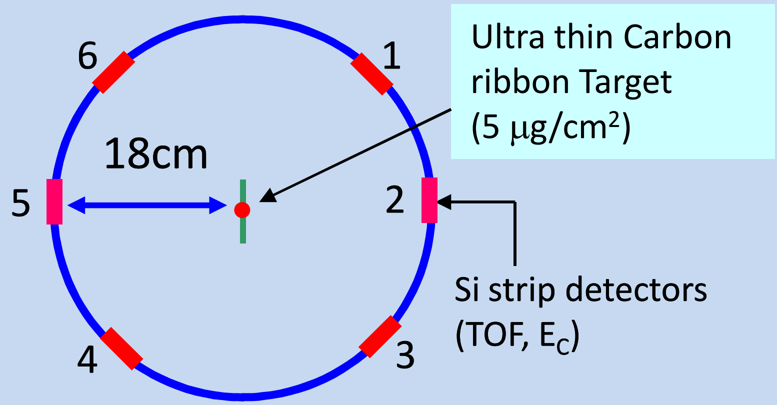
Problems reproduced at AGS in Run 2010

No problems with new FEE (faster amplifiers)

AGS tests, Mar 2010



Improvements in pC



Significantly upgraded before Run9:

Two independent polarimeters in each ring
(but using the same DAQ)

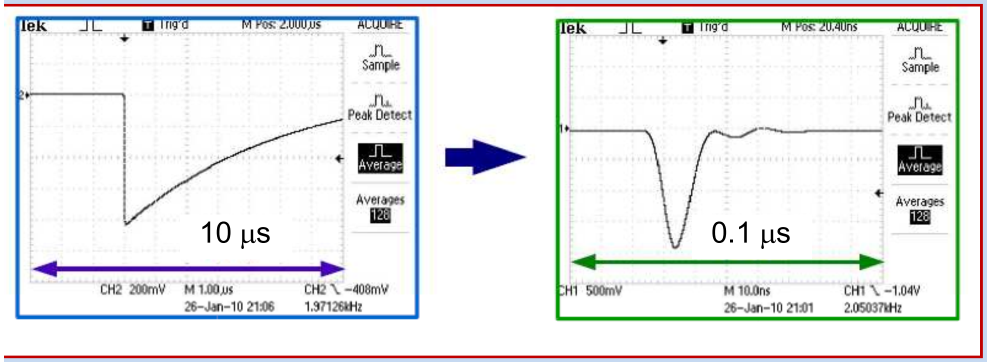
- ✓ Improved vacuum chamber
- ✓ New target holders
  - Better target positioning
  - 6 vertical and 6 horizontal targets in each polarimeter – enough for long Run
  - ~Simultaneous measurements of vertical and horiz. polarization profiles
- ✓ 6 detectors in each polarimeter
  - Slots to test new detectors

pC+Hjet: Path Forward

Towards $\delta P/P<3\%$

Old amplifier

New amplifier

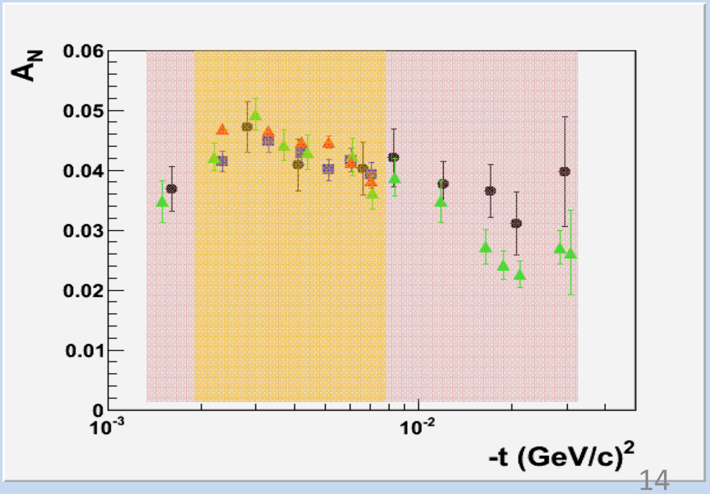


pC:

- ✓New FEE (faster preamplifiers): to be replaced before Run 11
- ✓New type of detectors (radiation hard, uniform, better resolution, less sensitive to background)
- ✓DAQ upgrade (from CAMAC to VME, possibly from WFD to ADC/TDC)
- ✓Slow control / Monitoring
- ✓Tools for machine experts

HJet:

- ✓New type of detectors with possibly extended acceptance (larger statistics ⇒ better precision)
- ✓Better control of molecular (and other) background (becoming a dominant source of syst. uncertainties)



Local Polarimetry

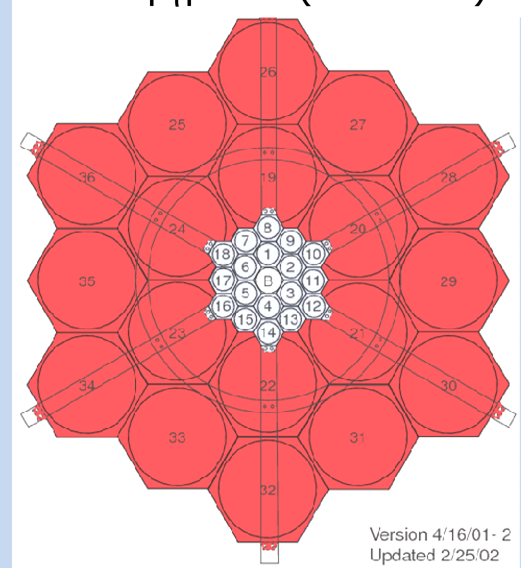
PHENIX:

Utilizes spin dependence of very forward neutron production discovered in RHIC Run-2002 (PLB650, 325)

A_N ($\sqrt{s}$=200 GeV) ~ 7%

Beam energy dependent (A_N increases with $\sqrt{s}$)

Beam-Beam Counters
$3.3<|\eta|< 5.0$ (inner tiles)



STAR:

Detects forward hadron in BBC acceptance

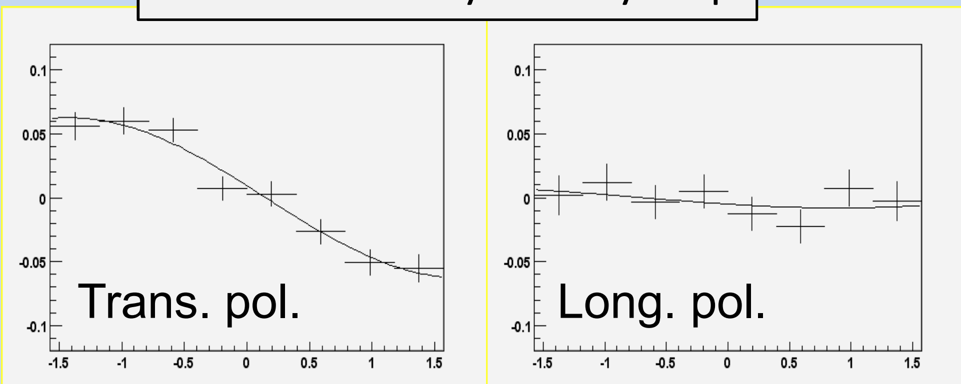
A_N ($\sqrt{s}$=200 GeV) ~ 0.7%

Beam energy dependent (A_N decreases with $\sqrt{s}$)

(Also ZDC based polarimeter commissioned in Run9)

Local Polarimetry

PHENIX ZDC: Asymmetry vs ϕ

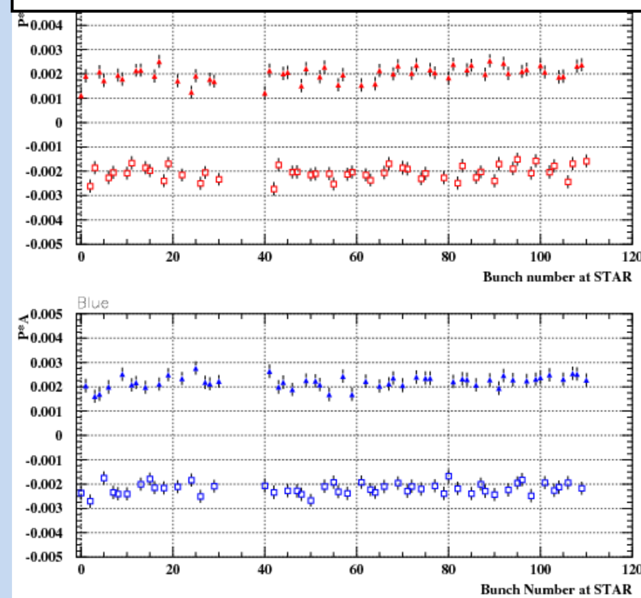


Monitors spin direction in collision region

Measures transverse polarization P_T ,
Separately P_X and P_Y

Longitudinal component: $P_L = \sqrt{P^2 - P_T^2}$
P – from CNI polarimeters

STAR BBC: Asymmetry vs bunch #



Precise polarization monitor
(for trans pol. beams):

Bunch by bunch

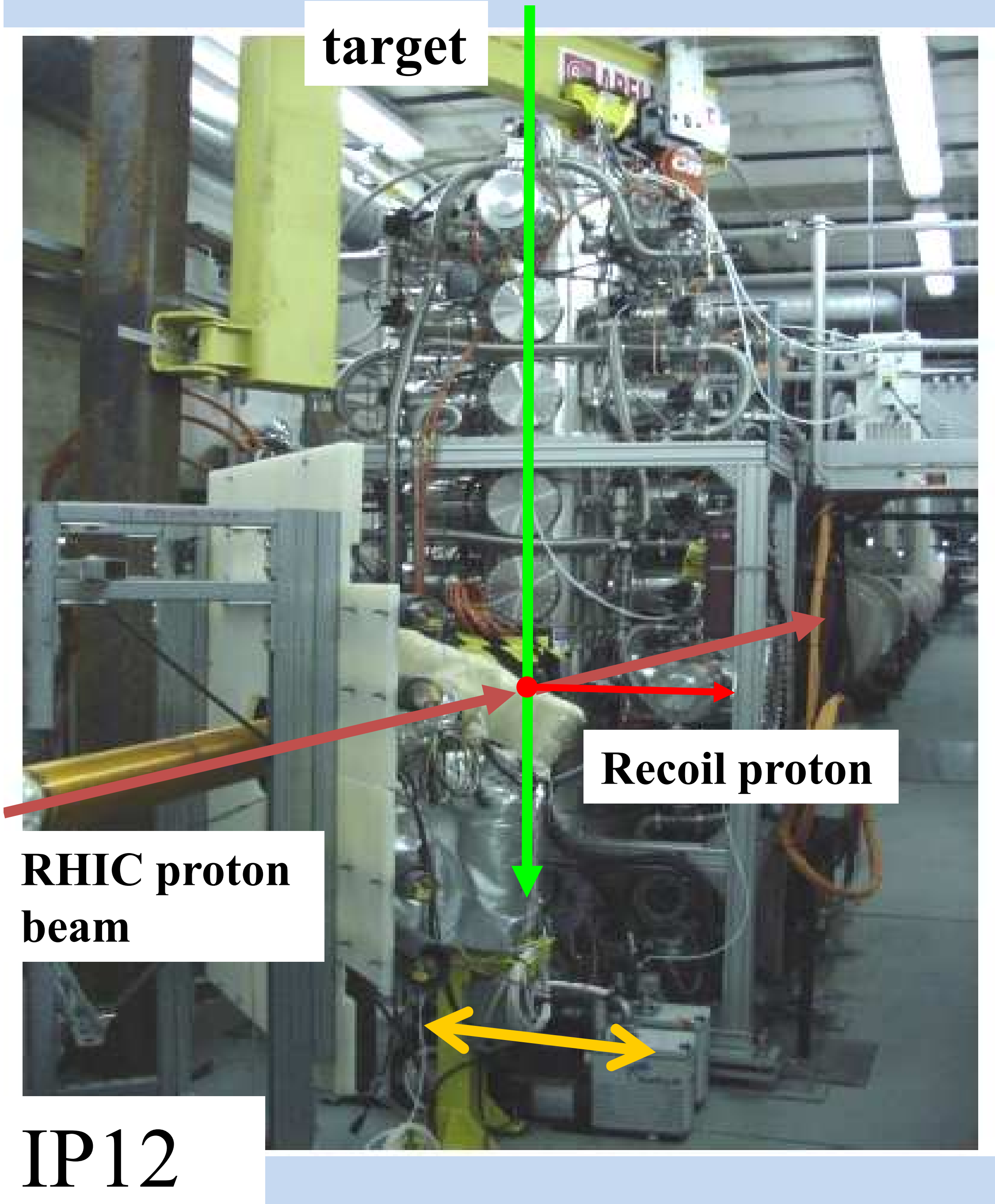
vs time in a fill

Summary

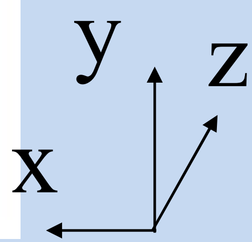
- RHIC Polarimetry consists of several independent subsystems
  - Hjet:
    - Absolute polarization measurements
  - pC:
    - Polarization monitoring vs bunch and vs time in a fill
    - Polarization profile
  - PHENIX and STAR Local Polarimeters:
    - Monitor spin direction (through trans. spin component) at collision
    - Polarization vs time in a fill and vs bunch (for trans. pol. beams)
- Provides crucial information for RHIC pol. beam setup, tune and development
- Provides precise RHIC beam polarization measurements
  - With relative uncertainty $\delta P/P<5\%$
- Continuously developing
  - Vacuum chamber upgraded by Run-2009
  - Experienced high rate related systematics from pC in Run9 $\sqrt{s}$=500 GeV $\Rightarrow$ faster FEE (by next RHIC Run)
  - Future upgrades: target system, detector, DAQ to deal with high beam luminosity, and to improve precision, efficiency and reliability

Backups

H-jet system

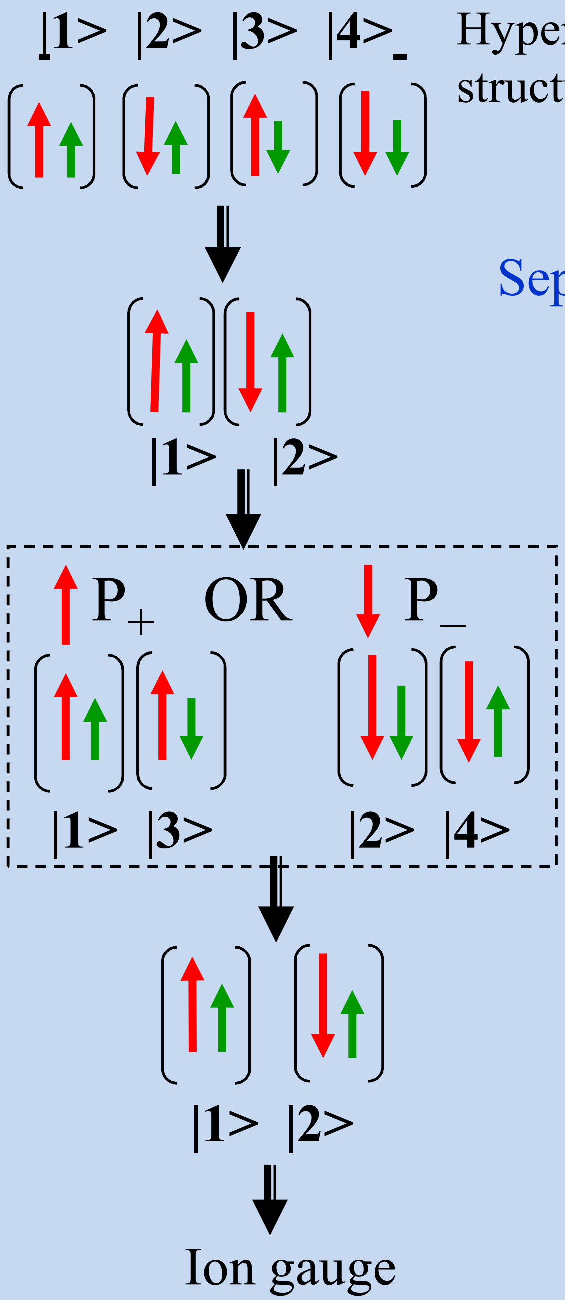


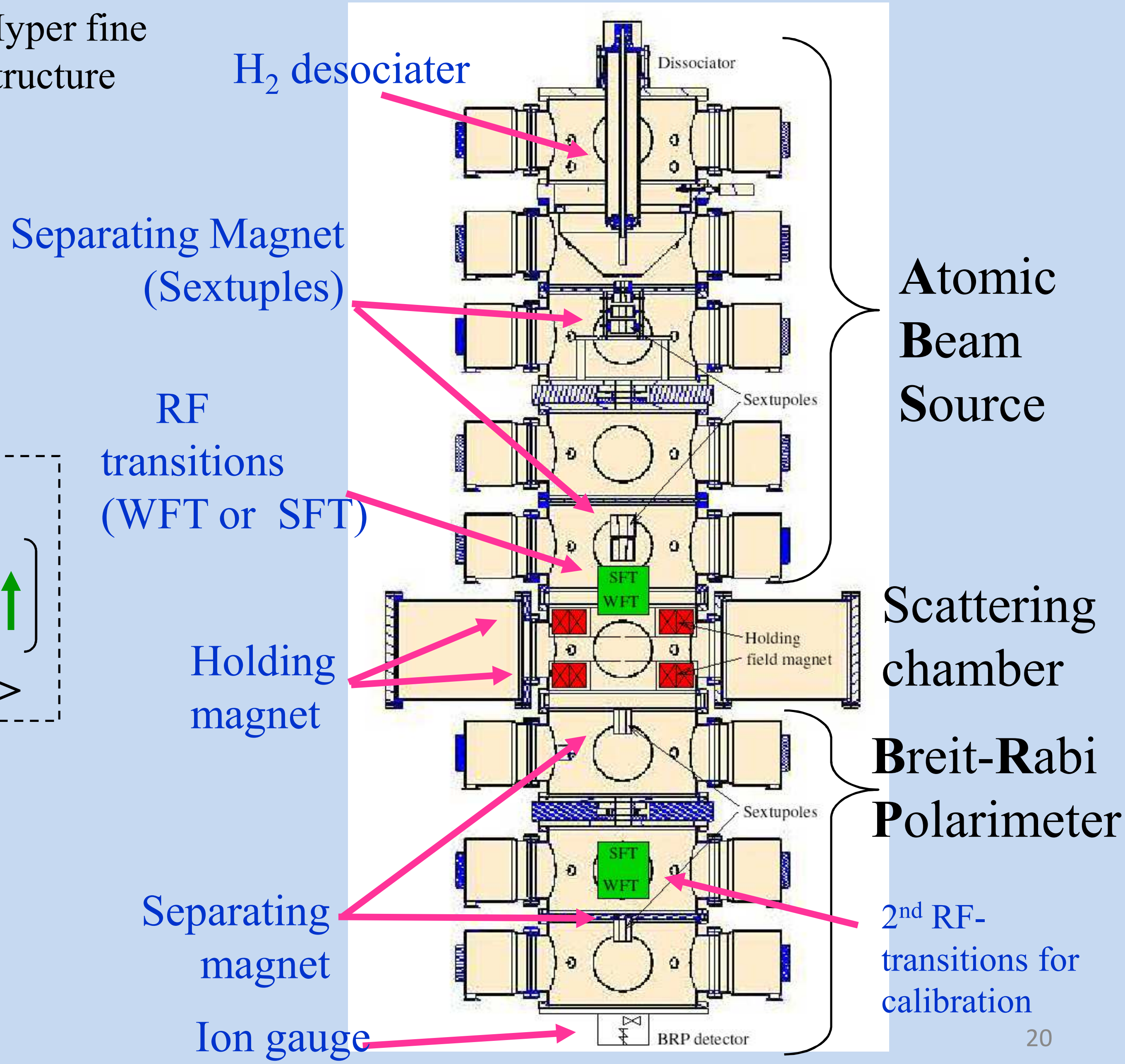
- Height: 3.5 m
- Weight: 3000 kg
- Entire system moves along x-axis –10 ~ +10 mm to adjust collision point with RHIC beam.



HJet target system

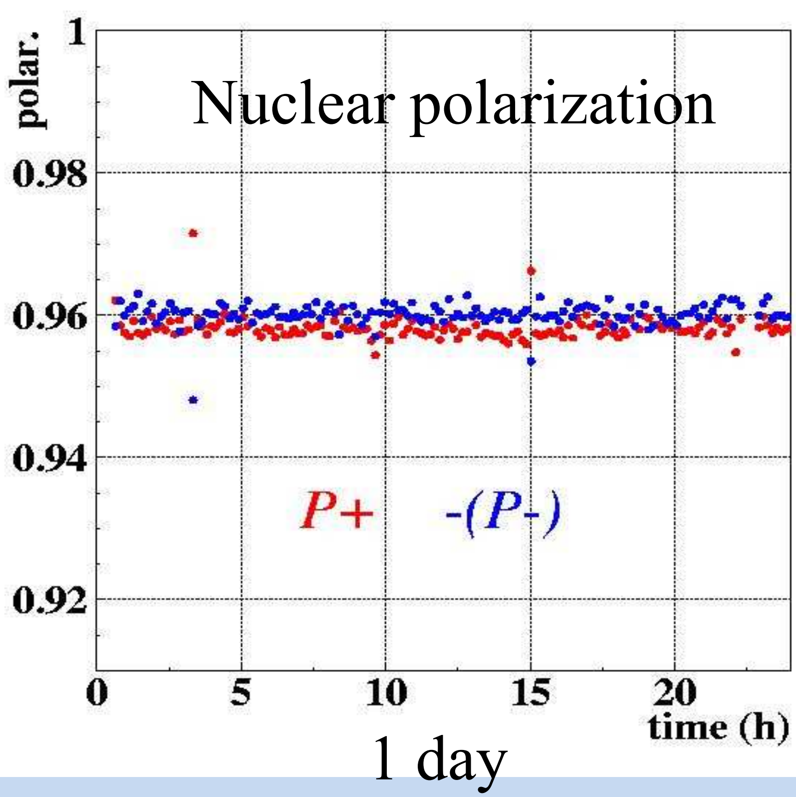
$$H = p^{+} + e^{-}$$





HJet: P_{target}

Source of normalization for polarization measurements at RHIC



Polarization cycle
(+/ 0/ –) = (500/50/500) seconds

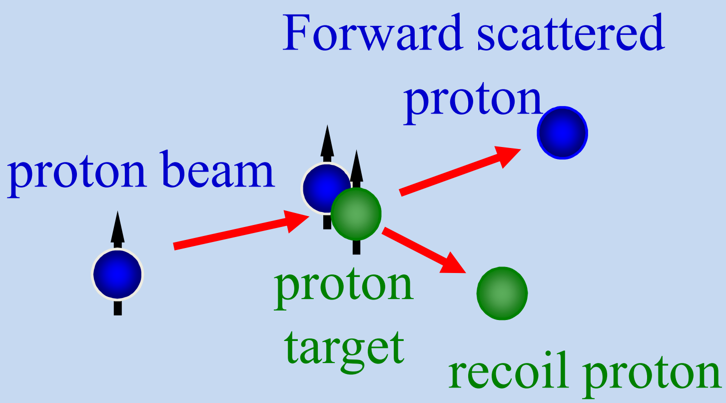
Very stable for entire run period !

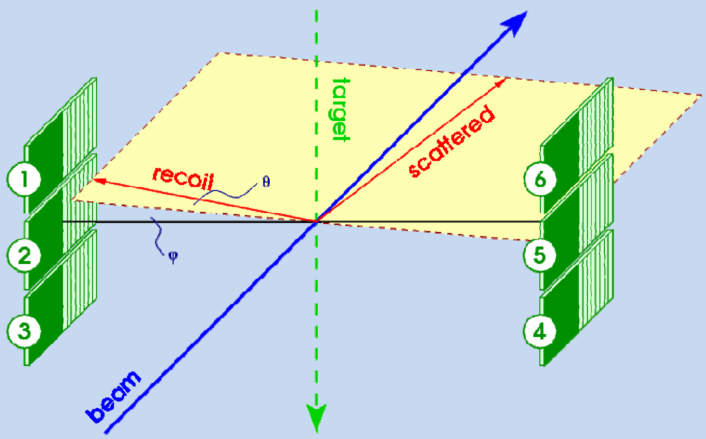
Nuclear polarization of the atoms measured by BRP: 95.8% ± 0.1%

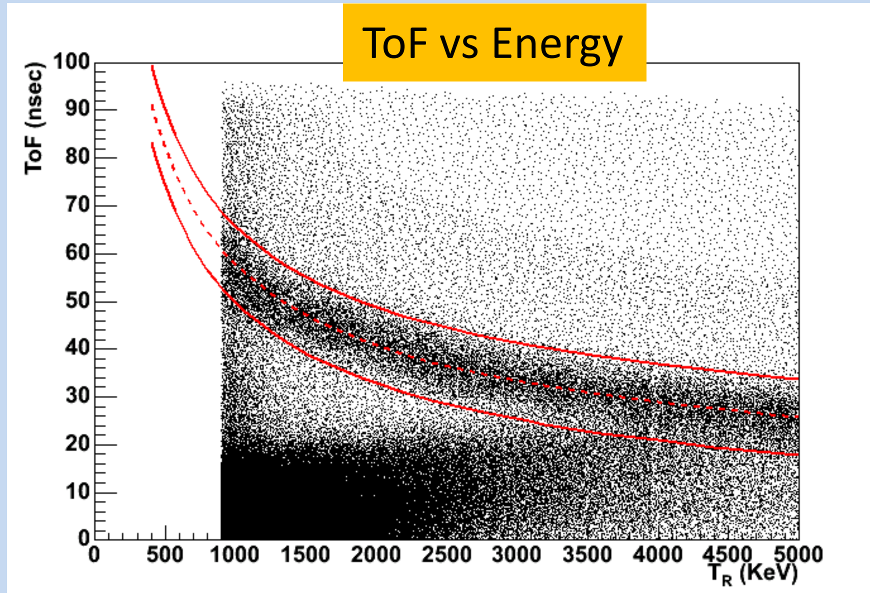
Correct for H_2, H_2O contamination.

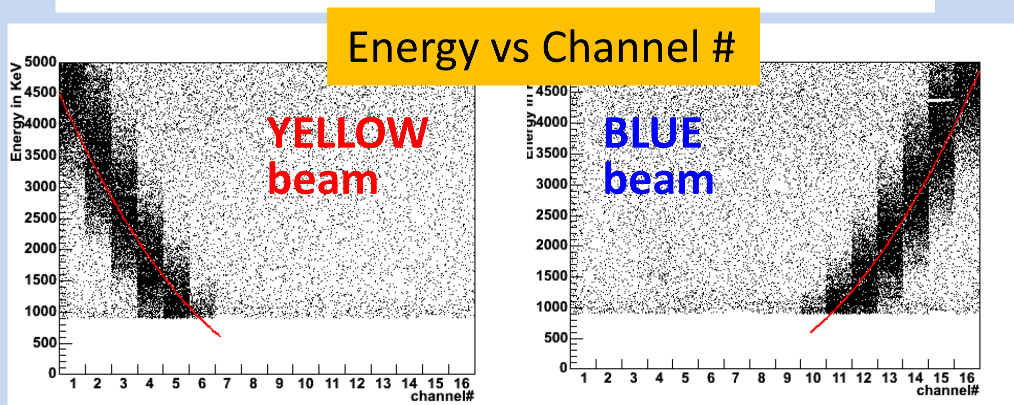
P_{target} = 92.4% ± 1.8%

HJet: Identification of Elastic Events





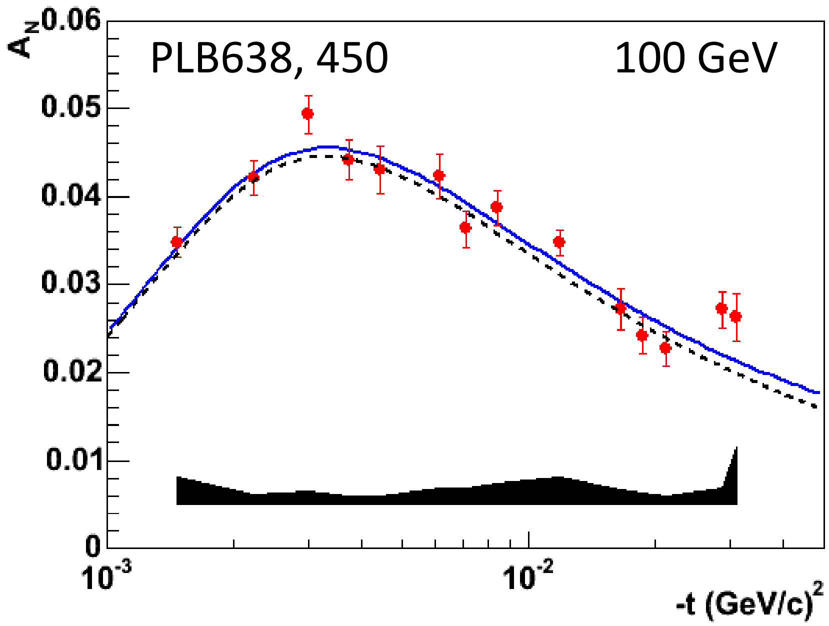


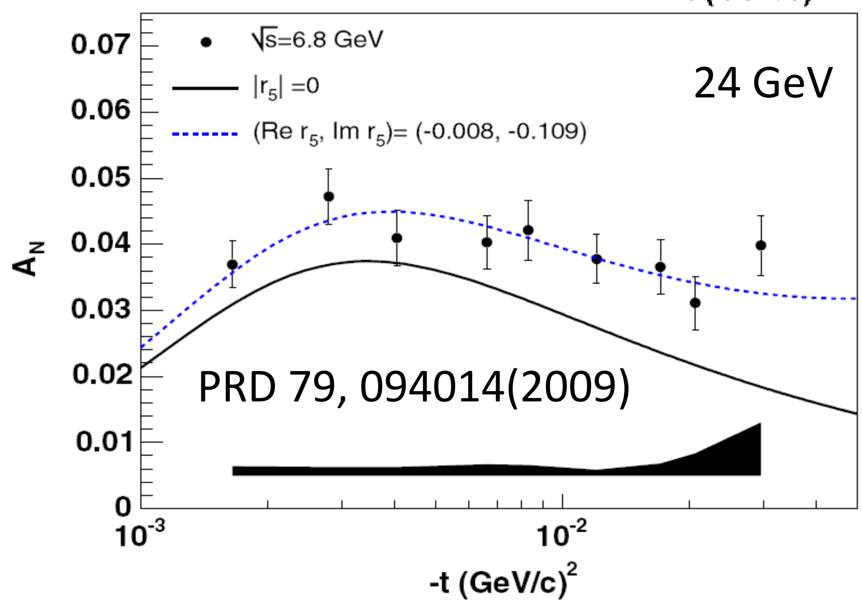


Array of Si detectors measures T_R & **ToF** of recoil proton.
Channel # corresponds to recoil angle θ_R.
Correlations (T_R & ToF) and (T_R & θ_R) → the elastic process

HJet: A_N in pp

$$A_N^{pp} = \frac{\varepsilon_{\text{target}}}{P_{\text{target}}}$$





$$A_N \approx \mathrm{Im}\left(\phi_{SF}^{em}\,\phi_{NF}^{had} + \phi_{SF}^{had\,*}\,\phi_{NF}^{em}\right) \Big/ \left|\phi_{NF}^{had}\right|^2$$

100 GeV: calculations with no hadronic spin flip amplitude contribution are consistent with data

24 GeV: calculations with no hadronic spin flip amplitude contribution are not consistent with data

pC: goals/strategy

Polarization measurements for experiments

- Target Scan mode
  - Provides polarization at beam center, polarization profile, average polarization over profile
- 20-30 sec per measurement
  - For stat. precision 2-3%
- 4-5 measurements per fill (every 2-3 hours), per ring
  - Controls polarization decay vs time in a fill
- Polarization profile, both vertical and horizontal
- Normalized to HJet measurements over many fills
  - Knowledge on polarization profile in one transverse direction is required
- Fill-by-fill polarization
  - Knowledge on polarization profile in both transverse directions is required

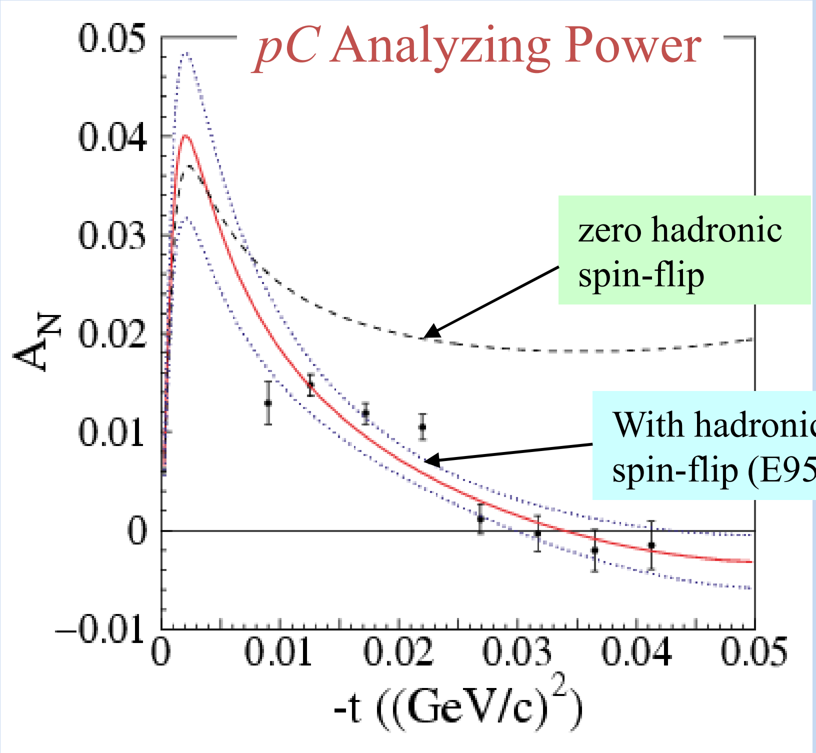
Feedback for accelerator experts

- Beam emittance measurements, bunch-by-bunch
- Polarization profile, both vertical and horizontal
- Polarization (and polarization decay in a fill)
- Polarization at injection (and polarization loss in transfer)
- Polarization on the ramp (and polarization loss during ramp)

pC: A_N

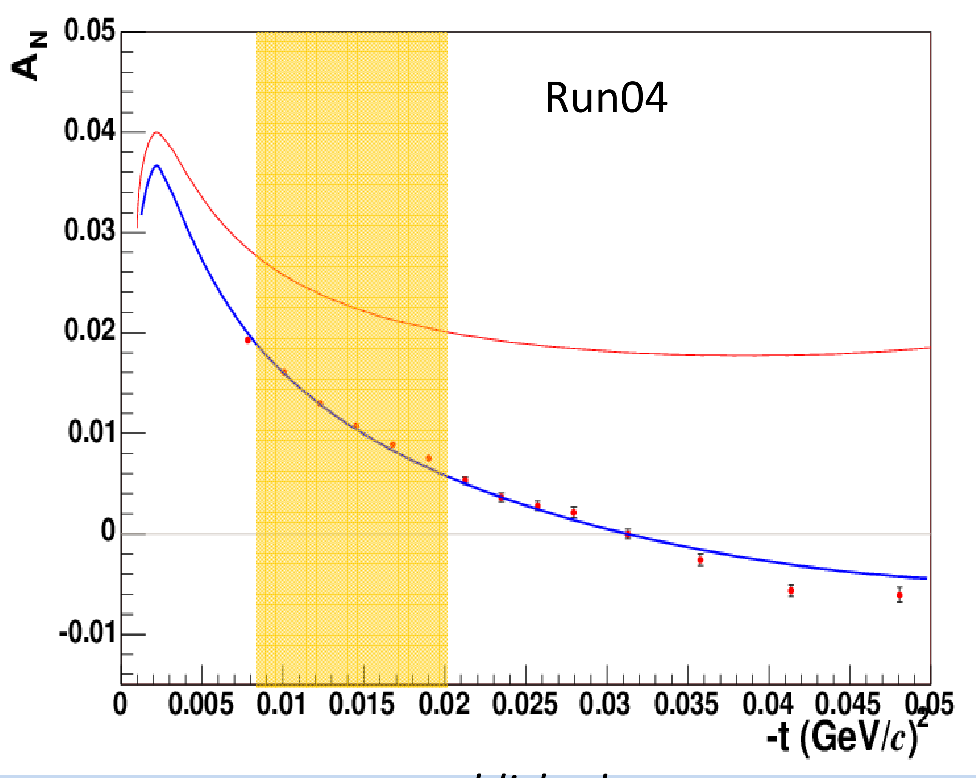
Elastic scattering: interference between electromagnetic and hadronic amplitudes in the Coulumb-Nuclear Interference (CNI) region

$$A_N \approx C_1 \phi_{flip}^{em\,*} \phi_{non-flip}^{had} + C_2 \phi_{non-flip}^{em\,*} \phi_{flip}^{had}$$



Phys.Rev.Lett.,89,052302(2002)

E_{beam} = 21.7GeV



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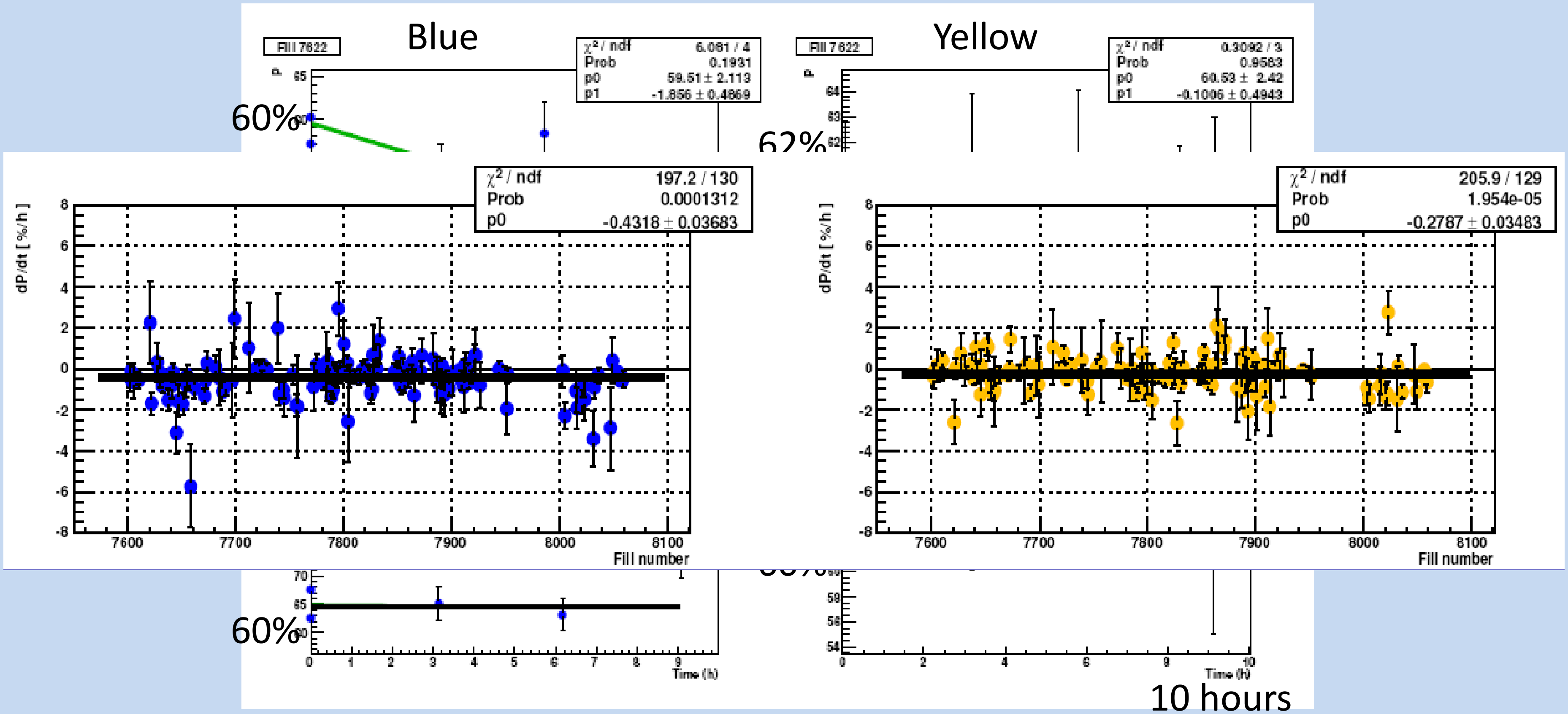
E_{beam} = 100 GeV

pC: polarization in a fill

Example from Run-2006



Some fills may show polarization decay vs time
Run6: average polarization drop during a fill 0.3-0.4% per hour

Average Polarization

$$P(x) = P_{\max} \cdot \exp\left(-\frac{x^2}{2\sigma_P^2}\right) \qquad I(x) = I_{\max} \cdot \exp\left(-\frac{x^2}{2\sigma_I^2}\right) \qquad R = \frac{\sigma_I^2}{\sigma_P^2}$$

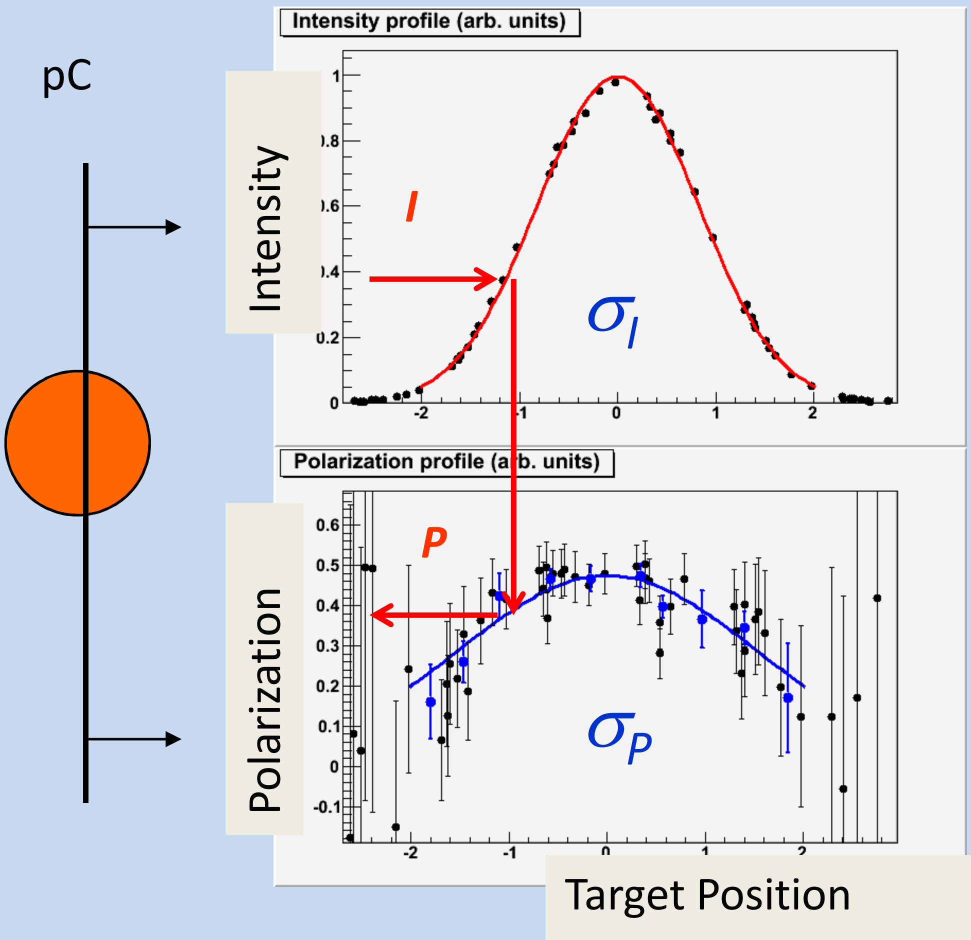
H-Jet	$\langle P \rangle = \dfrac{\int P(x,y) I(x,y) dx}{\int I(x,y) dxdy} = \dfrac{P_{\max}}{\sqrt{1+R_X}}$	
pC	$\langle P \rangle = P_{\max}$	If target positioned at beam peak intensity/polarization
Collider Experiment	$\langle P \rangle = \dfrac{\int P(x,y) I_1(x,y) I_2(x,y) dxdy}{\int I_1(x,y) I_2(x,y) dxdy} \approx P_{\max} \dfrac{\sqrt{1+\frac{1}{2}R_Y}}{\sqrt{1+\frac{1}{2}R_X}}$	If $\sigma_{I1} = \sigma_{I2} = \sigma_I$

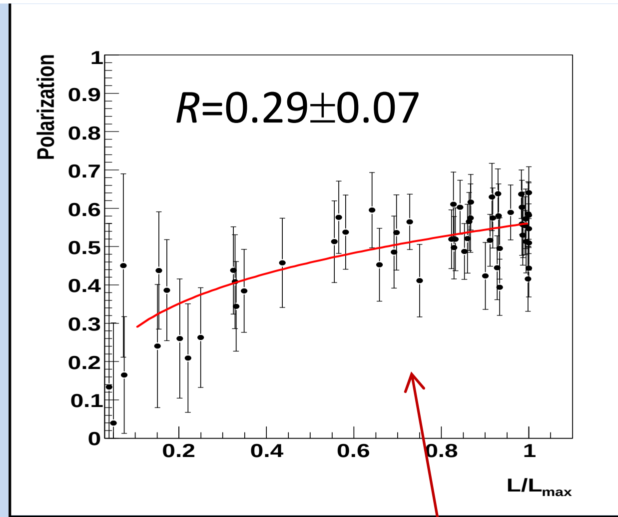
Corrections due to polarization profiles are different when normalizing pC to H-Jet and when propagating pC measurements to experiments

Polarization profile in both trans. directions (X,Y) required

pC: Polarization Profile

Scan C target over the beam cross:





1. Directly measure σ_I and σ_P:

$$R = \frac{\sigma_I^2}{\sigma_P^2}$$

2. Obtain R directly from the *P*(*I*) fit:

$$\left.\begin{aligned} P(x) &= P_{\max} \cdot \exp\left(-\frac{x^2}{2\sigma_P^2}\right) \\ I(x) &= I_{\max} \cdot \exp\left(-\frac{x^2}{2\sigma_I^2}\right) \end{aligned}\right\} \quad P = P_{\max} \cdot \left(\frac{L}{L_{\max}}\right)^R$$

Precise target positioning is NOT necessary

pC: Run-2009 issues

Measurements for 100 GeV and 250 GeV beams

Sizable rate dependencies ($\times$3 higher rates than previously)

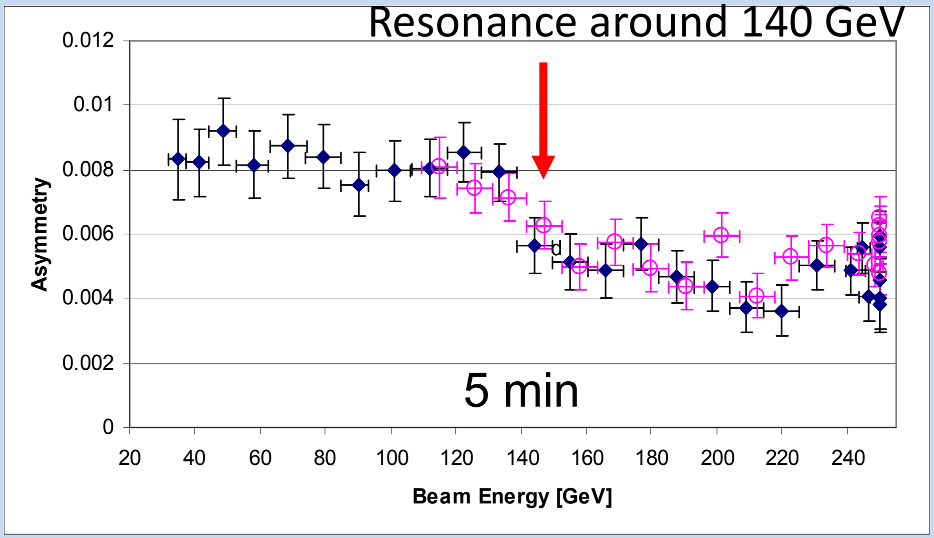
- Targets appeared to be wider than expected
- Higher beam intensity for 100 GeV (1.7×10^{11} /bunch in 109 bunch pattern)
- Smaller beam size for 250 GeV

Substantial pC-system upgrade is being considered:

- Better (thinner and uniform) target production
- More robust detectors, smaller acceptance
- Faster preamps
- Replace WFD with simple ADC/TDC scheme?

pC for RHIC pol. beam set up, tune and development

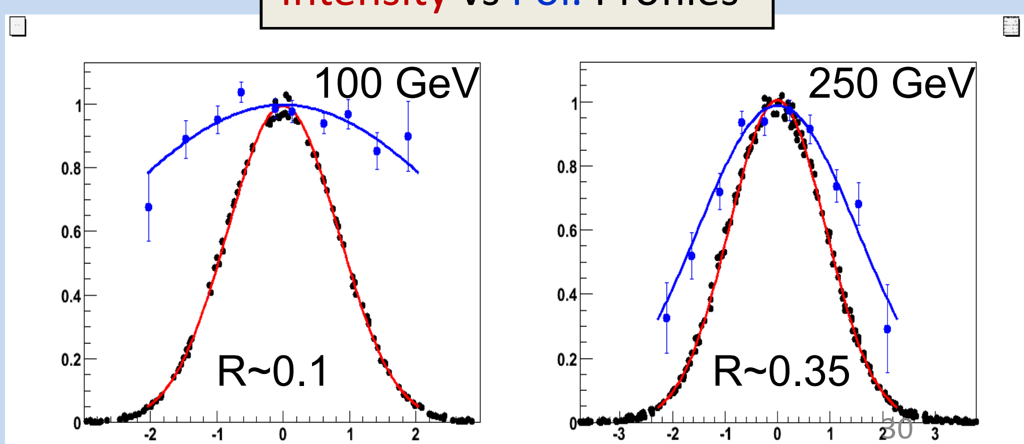
Run-2009



Consistent with no polarization loss on the acceleration ramp between RHIC injection and 100 GeV

Polarization loss on the ramp between 100 and 250 GeV

Intensity vs Pol. Profiles



Sharper pol. profile for 250 GeV beams compared to 100 GeV beams
(No pol. profile change from AGS to RHIC 100 GeV)

Studied for different RHIC setups

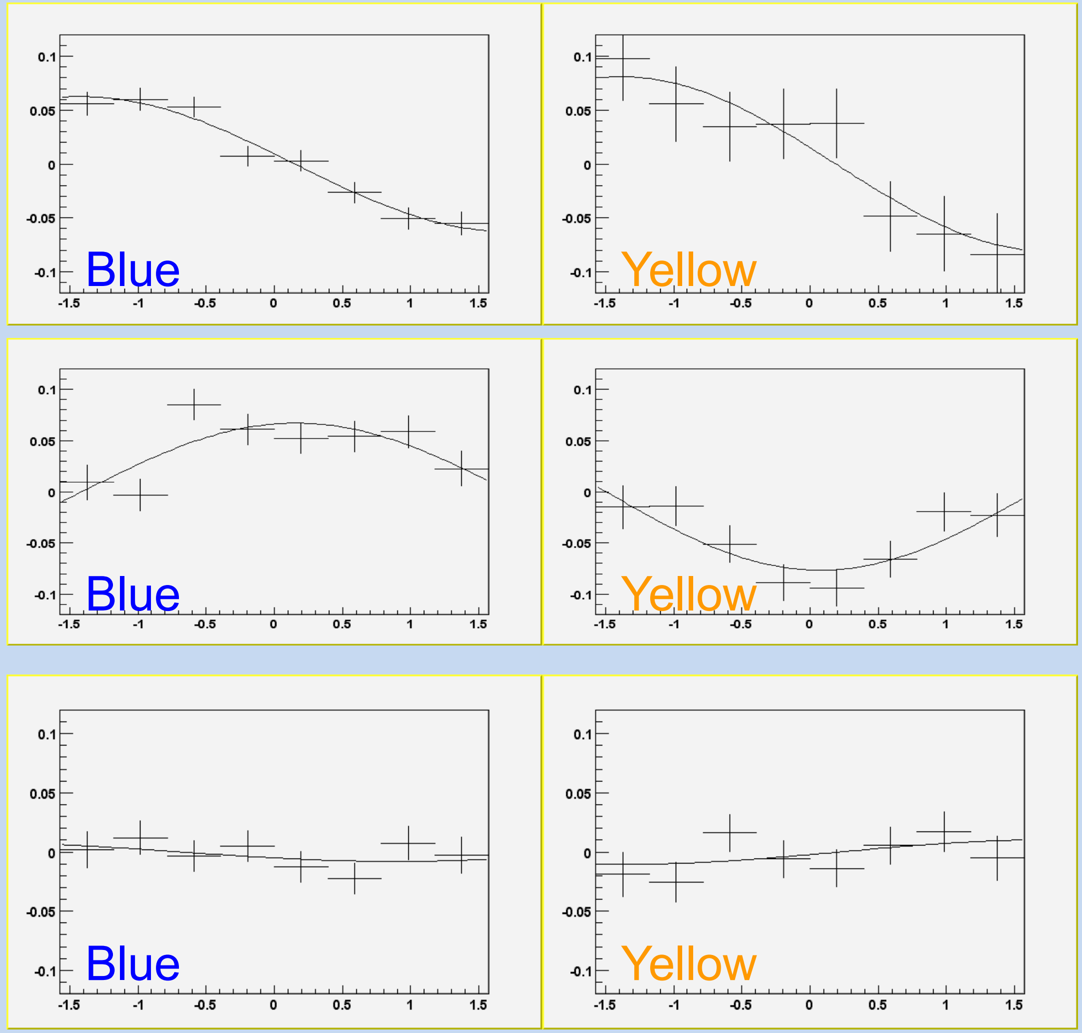
PHENIX Local Polarimeter

PHENIX ZDC: Asymmetry vs ϕ

Spin Rotators OFF
Vertical polarization

Spin Rotators ON
Current Reversed
Radial polarization

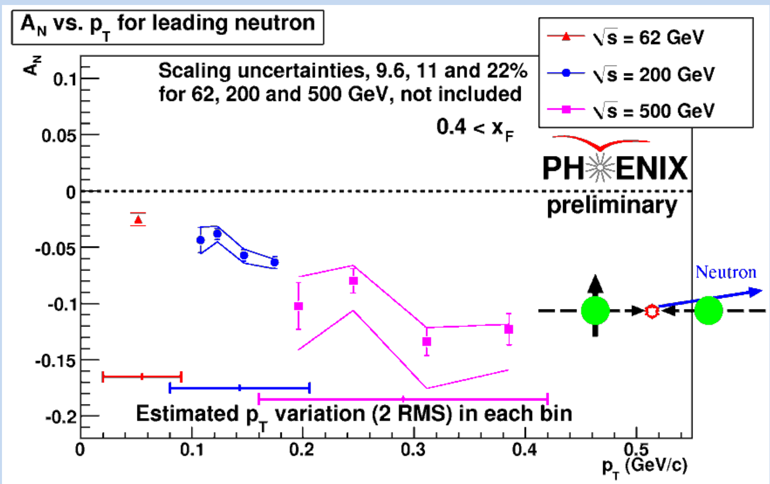
Spin Rotators ON
Correct Current !
Longitudinal polarization!



Monitors spin direction in collision region

PHENIX Local Polarimeter

Utilizes spin dependence of very forward neutron production discovered in RHIC Run-2002 (PLB650, 325)



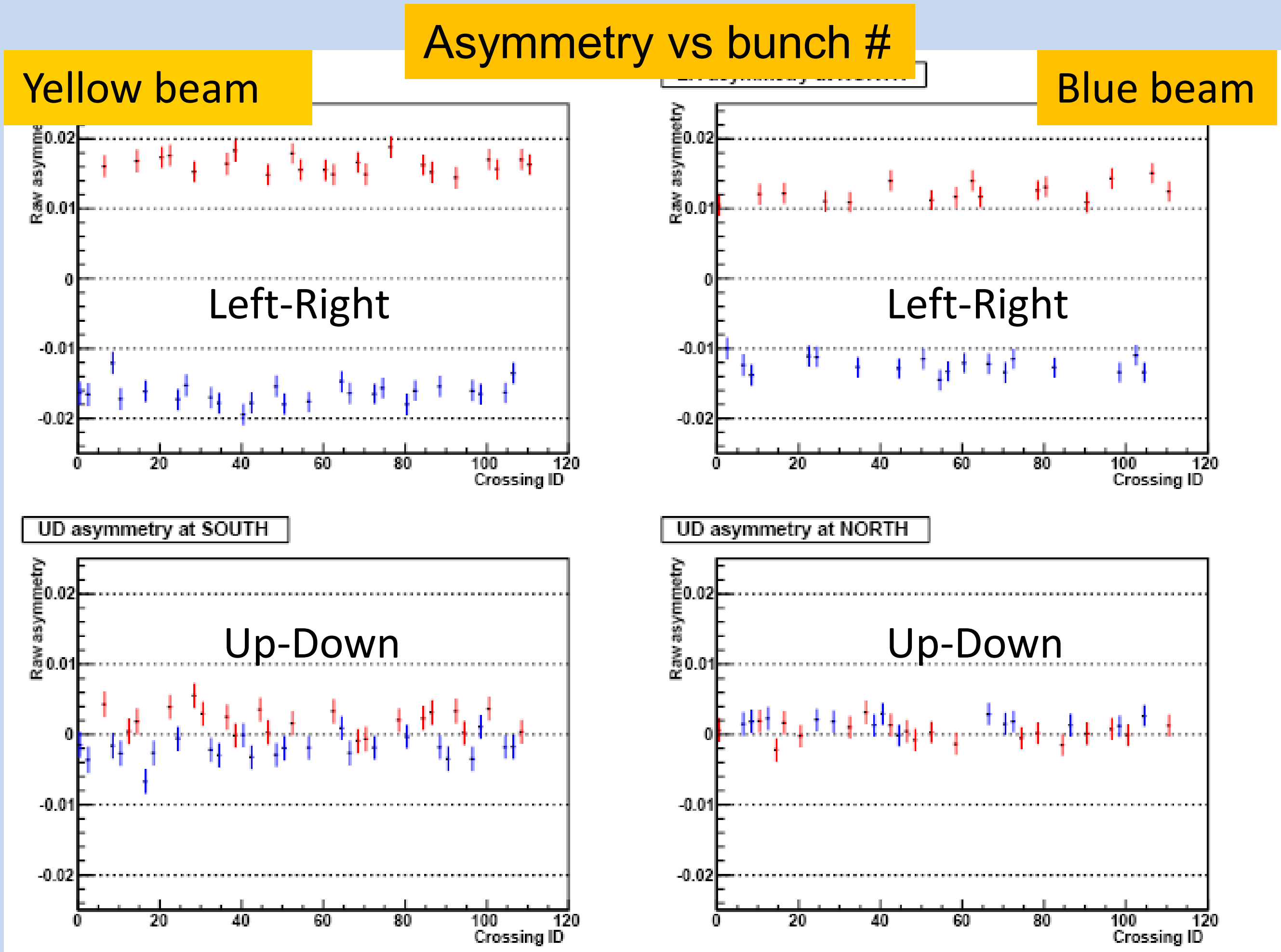
ZDC (energy) + SMD (position)

- ✓ Controls spin vector in runs with trans. polarized protons
- ✓ Controls residual trans. polarization in runs with long. polarized protons
- ✓ Capable to precisely monitor polarization decay vs time in a fill and bunch-by-bunch polarization (in trans. pol. runs)

PHENIX Local Polarimeter

Run-2009

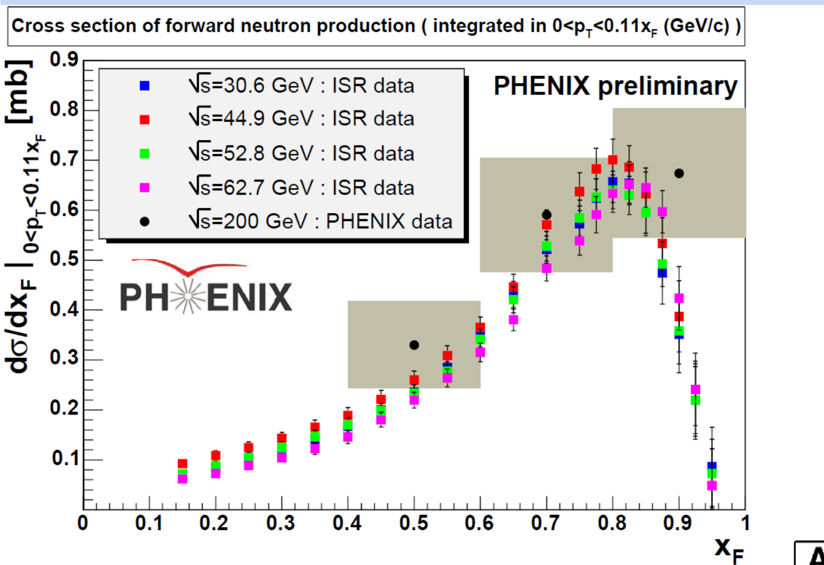
5 min data !
(in scaler mode)



Precisely monitors bunch-by-bunch polarization and polarization vs time in a fill
(for transversely polarized beams)

PHENIX Local Polarimeter: energy dependence

See M.Togawa talk at PST-09 next week



$d\sigma/dx_F$ is nearly energy independent $\Rightarrow$

$\langle p_T\rangle_{ZDC}$ ~ Beam_Energy (or $\sqrt{s}$)

$A_N \sim p_T \;\Rightarrow\; A_N \sim \sqrt{s}$
in fixed ZDC geometry

$\Rightarrow$ polarimetry is less efficient for lower beam energy